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WIND FORCE AND EXCEPTIONAL VISIBILITY AT SEA

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Visibility depends upon numerous factors, including many properties of the object used as a visibility mark, and variable conditions of light and atmosphere.[1] Studies of visibility have been made on land, and to some extent on seacoasts, but little has been done for the open sea. Actually, there are seldom in the open sea any marks for estimating visibility beyond small distances in the terms of a ship's length. An international scale [2] is in use on shipboard but it depends largely on rough estimates.

For many years seamen have entered the Beaufort symbol "v" in their meteorological logs to indicate abnormal clearness and transparency of the atmosphere. "With such exceptional visibility distant objects stand out from their background with great distinctness and show more sharply-defined detail than usual."[3] At the other end of the scale, where horizontal visibility at sea is very poor, the obscuration is almost always due to fog, which is carefully recorded. The records of "v" will be discussed here in relation to wind velocity.

It has been the general conclusion that an increase in wind velocity tends to increase the horizontal visual range, by carrying to higher levels the dust particles that tend to accumulate in the lower atmosphere. This definitely applies to land observations except in deserts and other regions where increased wind carries appreciable amounts of fresh dust or sand into the air. In previous studies, some records at coastal stations seemed to indicate that the reverse is true there, that is, the visual range diminishes as the wind velocity increases. For example, Dines and Mulholland,[4] dealing with observations made at Valencia Observatory, on the extreme west coast of Ireland, found it noticeable that exceptionally good visibility denoted by the letter "v" mostly occurred with light winds, and that the stronger winds between south-southeast and southwest had the worst visibility of all.

In the Marine Division of the U. S. Weather Bureau there are now available for study the data compiled from 5½ millions of observations from ships during a period of approximately 50 years.[5] From these compilations we have, by 5° squares, average wind forces converted to knots and the percentage frequency of observations of "v". These values have been computed by months and seasons. Winter includes December, January, and February; spring comprises March, April, and May; etc. Annual values have also been computed.

Taking annual values for all 5° squares of the Pacific Ocean north of the 20th parallel of north latitude, we have available as a basis for study very nearly 700,000 observations. The annual averages of these 5° squares, when assembled to show frequency of exceptional visibility in squares with certain wind velocities, appear in figure 1. Here, for example, the visibility value of 8.8 percent plotted against an average wind velocity of 8 knots (value "A" in figure 1) is determined as follows: All squares with an average annual wind movement of 8 knots are segregated and the average annual frequency of exceptional visibility is determined for all of these squares

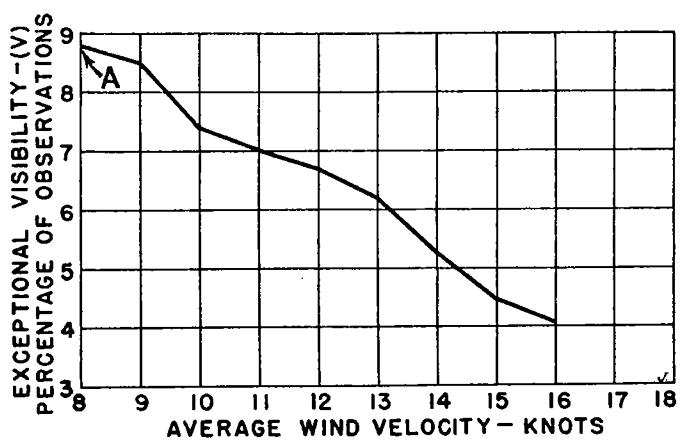

Figure 1.—Frequency of exceptional visibility as related to average wind velocity. Data for the North Pacific Ocean; annual values by 5° squares north of 20° N. Frequency of exceptional visibility ("v") is the ratio of observations of "v" to the total number of observations, expressed in percent.

combined. The same is done for squares with other velocities. The results seem to indicate a definite tendency for the range of visibility to diminish with increase of wind velocity. Values for velocities below 8 knots and above 16 knots are not included as they were too few in number to make a dependable showing.

This does not mean necessarily that there is a reduction in the range of visibility when the wind increases from 8 to 10 knots, for example. These are average values and it is assumed that strong winds are more frequent when the average velocity is 10 knots than when it is 8.

In this tabulation there is a geographical effect which renders the results questionable. Wind velocity is generally higher in high latitudes of the North Pacific than in low latitudes, hence the majority of squares with light winds are in low latitudes and vice versa. On the other hand, fog is more prevalent in high latitudes generally, thus favoring reduced visibility with the lower wind

[1] Middleton, W. E. Knowles. *Visibility in Meteorology.* Toronto, 1935.
[2] International Meteorological Organization. *Publication No. 9,* Fascicule I. Leyde, 1936.
[3] Meterological Office, Air Ministry. *The Marine Observer's Handbook.* London, 1937.
[4] Dines, L. H. G., and Mulholland, P. I. On the interrelation of wind direction with cloud amount and visibility at Cahirciveen, Co. Kerry. *M. O. Professional Notes,* Vol. 3, No. 36. London, 1924.
[5] McDonald, W. F. *Atlas of Climatic Charts of the Oceans.* Washington, 1938.

velocities there. However, another tabulation has been made, using the squares between 10° and 30° north latitude, by seasons (more than 300,000 observations) and the results are shown in figure 2 where the method of compilation is the same as in figure 1 except that seasonal instead of annual values are used. In general there is not

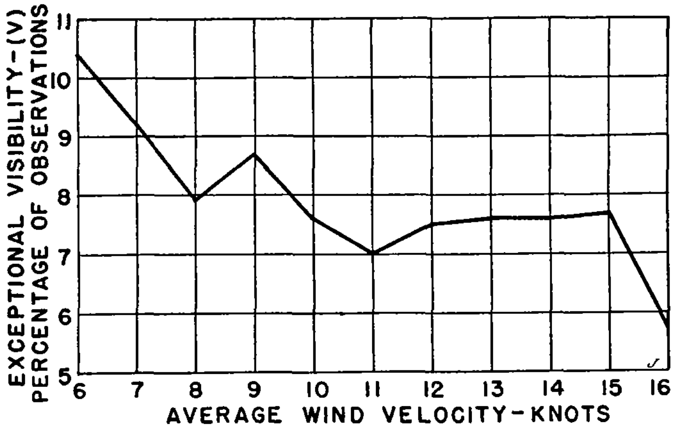

FIGURE 2.—Frequency of exceptional visibility as related to average wind velocity. Data for the North Pacific Ocean; seasonal values by 5° squares between 10° and 30° N. Frequency of exceptional visibility ("v") is the ratio of observations of "v" to the total number of observations, expressed in percent.

a pronounced variation of wind velocity with latitude in this region (10° to 30° N.), and furthermore there is not nearly so much fogginess here in summer as in higher latitudes. Figure 2 indicates that there is in general a lessening of the visual range with increase of wind move-

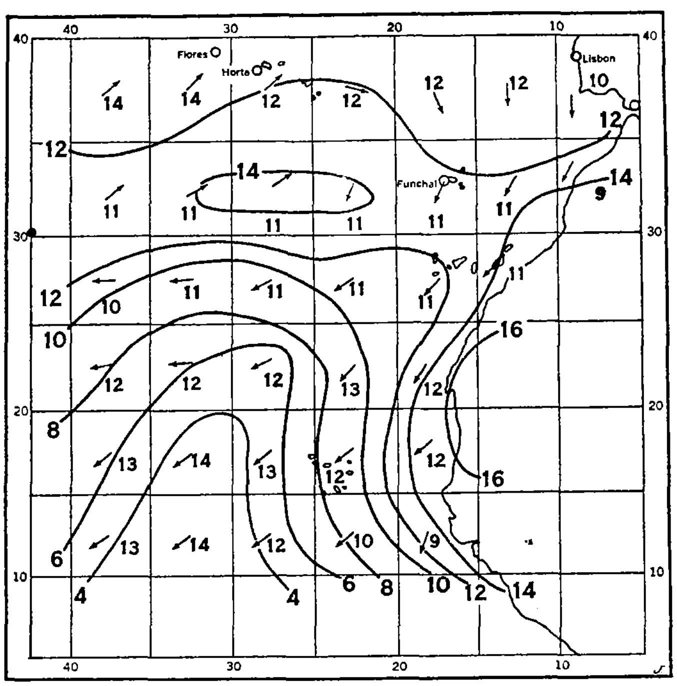

FIGURE 3.—Annual frequencies of exceptional visibility in percent (solid lines), average annual wind velocity (numbers in squares), and prevailing wind directions for the year (arrows flying with the wind).

ment. Sampling of data in other oceans gives similar indications.

Figure 3 shows the relation of the trade winds to the frequency of exceptional visibility in the southeastern North Atlantic. Here we have annual averages of exceptional visibility shown by isograms, the annual wind velocities in knots shown by figures in each 5°—square, and the prevailing wind directions for the year shown by arrows flying with the wind. It will be seen that the frequency of exceptional visibility diminishes progressively outward from the continent of Africa in the region of the trade winds. On the other hand, we see in figure 4 that the annual percentages of haze in ships' observations diminish outward from Africa. Thus it appears that dust

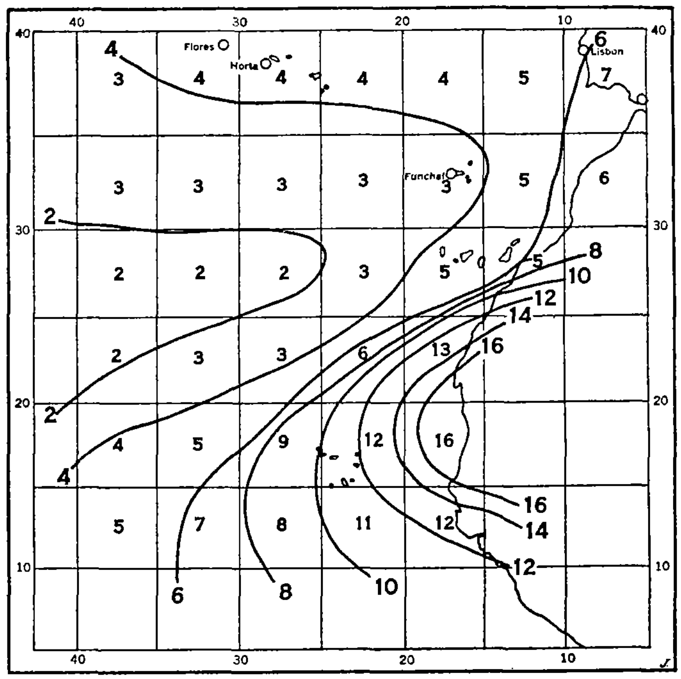

FIGURE 4.—Annual frequency of haze in percent shown by solid lines and by numbers in squares.

carried from Africa is most frequent near the coast but this does not result in lower values of the frequency of exceptional visibility near the coast. On the contrary the frequency of exceptional visibility diminishes to the leeward of the trade winds.

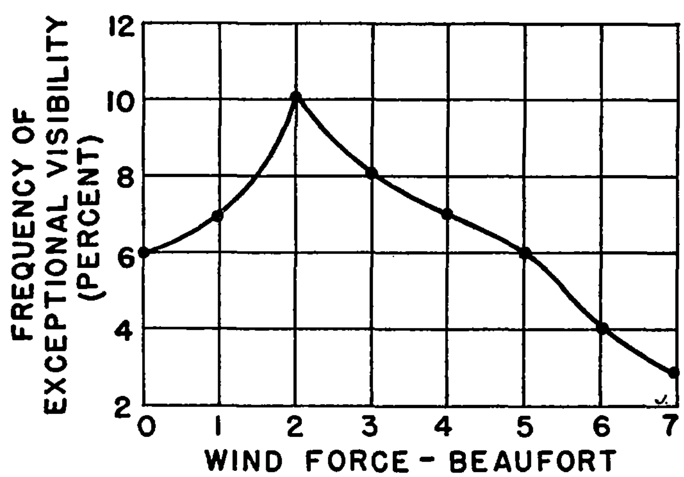

FIGURE 5.—Relation of the frequency of exceptional visibility to wind force in 18,966 ships' weather observations. Complete data are given in the table.

The results of an effort to determine the relation of wind force to the frequency of "v" in individual marine observations are shown in figure 5. In the Pacific area bounded by the Equator and the parallel of 15° north latitude and by meridians of 125° and 170° west longitude, there are available 19,261 ships' weather observations on punched cards. This area was selected because of its relatively high average wind velocity, absence of fog, and distance from continental areas. The observations were sorted by wind forces, and the occurrences of "v" for each force were tabulated. Figure 5 shows the frequency of "v" for the various wind forces from 1 to 7, inclusive; occurrences of calms are also included. The numbers of observations used in the figure, as shown in the accompanying table, ranged from 293 for force 7 to 5,615 at force 4. For the higher forces the numbers of observations ranged from 4 (force 12) to 84 (force 8). However, there were only 5 occurrences of exceptional visibility for a total of 124 observations of wind force exceeding Beaufort 7.

It will be noted that the frequency of "v" increases (figure 5) from "calm" to force 2, and diminishes as the wind increases from force 3 to force 7. This does not necessarily mean that an increase in wind velocity from force 2 to force 3 is the cause of a local reduction in the range of vision. The obscuration is probably a result of higher velocities to windward, which are more frequently associated with local winds of force 3 than force 2.

It is known that when winds of Beaufort forces 11 and 12 prevail, horizontal visibility is greatly reduced. In the scale of wind effects upon the sea surface as originally formulated by Petersen[6] and adopted internationally with slight modifications in 1939, the description applied to Beaufort force 12 includes the statement that the air becomes so filled with foam driven away from the sea-water that vision for any distance no longer exists. In the same scale, at Beaufort force 7, the white foam is carried in streaks in the direction of the wind; this sometimes occurs at force 6, but becomes more pronounced as the wind increases; salt spray is then an important factor in reducing the range of vision.

These facts were taken into consideration in preparing the definitions of hydrometeors adopted by the Weather Bureau in 1938. A definition of "damp haze," not in the international list,[7] was introduced to provide for recording observations of a phenomenon evidently caused by strong winds at sea and which should be differentiated from thin fog.

The remarks relating to damp haze [8] are:

Description.—Microscopically small water droplets or very hygroscopic particles suspended in the atmosphere, but the horizontal range of visibility is 1¼ miles or more, usually considerably more. Similar to a very thin fog, but the droplets or particles are more scattered than in ≡ (light fog), and presumably also smaller.

General instructions.—This hydrometeor is usually distinguished from dry haze (see "haze" above) by its grayish color, the "greasy" appearance of clouds seen through "damp haze" as though viewed through a dirty windowpane, and the generally high relative humidity. Commonly observed on seacoasts, and in Southern States, most frequently with onshore winds and in the vicinity of tropical disturbances. A common mode of formation of "damp haze" is the carrying up to high levels of particles from salt water spray in windy weather. In contrast, light fog is more commonly observed when there is little movement of the surface air.

Dines and Mulholland, in connection with the investigation previously mentioned,[4] state that so-called haze is as frequently seen at Valencia Observatory when the air is damp as when it is dry, and suggest that "the limitation of the term haze to occasions when the air is dry is not very satisfactory."

Wadsworth,[9] in a study of the relation between haze and relative humidity of the surface air, concludes that "the divergence in the results for the different observatories suggests that either there has been some confusion in the use of the terms haze and mist [10] or else other causes are at work which have not been taken into account."

Owens [11] in discussing the formation of a salt haze says:

It is evident, therefore, that the haze contained, if it did not entirely consist of, large numbers of salt crystals, and as they were probably at the time partly if not completely deliquesced, it appears to be a somewhat interesting condition—probably the transition state from a haze of dry crystals to a fog of liquid drops. It is important to note that the relative humidity at which the crystals were found to have deliquesced was 80 percent, while common salt is known to deliquesce at 74 percent to 75 percent relative humidity. The sea during the observation was rough, and doubtless one of the sources of the haze particles was the spray carried in the wind, but there was as well a large expanse of open foreshore over which sand was blowing, and this sand being wet with sea water doubtless set free salt particles into the wind.

CONCLUSION

Without considering the question of the proper designation of the phenomenon as one of a number of hydrometeors, it seems that the range of horizontal visibility on the seacoast and over the open ocean is frequently reduced because of the presence in the atmosphere of a haze composed of microscopically small water droplets or very hygroscopic particles, which is produced by the action of the wind on the sea surface, the obscuration increasing with the velocity of the wind. Stratification of the surface air, such as occurs sometimes when the sea surface is cooler than the air above it, tends to produce in low levels an accumulation of haze which is unfavorable for exceptional visibility. Ships' observations show that exceptional visibility is less frequently recorded with force 1 or calm than at force 2. At higher wind forces, however, the frequency of exceptional visibility diminishes as the wind increases. If this is true of visibility ranges in general, and not just the cases of "v" discussed here, we should expect to find an area of reduced visibility with its center lying to leeward of the central area of strong winds.

Wind force and exceptional visibility

Wind force (Beaufort)	Number of observations	Occurrences of exceptional visibility ("v")	Percentage frequency of "v"
Force not recorded	171	2	1
Calm	396	23	6
1	931	68	7
2	2,421	233	10
3	4,222	345	8
4	5,615	400	7
5	3,761	222	6
6	1,327	57	4
7	293	9	3
8	84	4	5
9	21	0	0
10	10	0	0
11	5	[1] 1	[1] 20
12	4	0	0
All observations	19,261	1,364	7

[1] The observations sorted from punched cards undoubtedly contain a few errors originating in the observations themselves or in punching the data. The occurrence at sea of exceptionally good visability with a wind of force 11 is quite unlikely, and this occurrence is probably an error. The original records are not available for verification.

[6] Petersen, P. Zur bestimmung der winstärke auf see. *Annalen der Hydrographie und Maritimen Meteorologie.* Heft III. Berlin, 1927.

[7] International Meteorological Organization. *Proces-Verbaux de la session de Salzbourg.* Pub. No. 40. Leyde, 1938.

[8] U. S. Weather Bureau. *Definitions of Hydrometeors and other Atmospheric Phenomena.* Washington, 1938.

[9] Wadsworth, J. The relation between haze and relative humidity of the surface air. *M. O. Professional Notes,* Vol. 3. No. 26. London, 1924.

[10] The term "mist," as used in the British Isles, is equivalent to a thin fog; presumably this is the meaning in Wadsworth's study.

[11] Owens, J. S. The making of a salt haze. *Phil. Mag.* 2: 1165-1170. London, 1926.